

The Effects of Multimedia and Elaborative Encoding on Learning

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February 7, 1996

(Technical Report GIT-GVU-96-05)

Keywords: Multimedia, elaborative encoding, learning

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Abstract

The effects of presenting information using multimedia (e.g., text, audio, illustrations) on learning performance are inconsistent. Some studies show that multimedia improves learning, while other studies find no effect. It is possible that these inconsistent findings may be explained by the effects of elaborative encoding. Elaborative encoding can be thought of as an encoding process that enriches a stimulus, therefore making it easier to store and retrieve the stimulus. For example, if pictures are richer than text, then multimedia that presents information using text and pictures may be more elaborative than multimedia that uses text and auditory words. Multimedia and learner tasks that encourage richer processing of the information may provide more links with which to connect the new information to prior knowledge. Information that is linked better may show higher levels of learning performance because the information is integrated with prior knowledge and more cognitive pathways are available to retrieve the information. (38 pages, 131 references)

Chapter 1 Introduction

When people try to learn information that is presented simultaneously by several different media (e.g., text and sounds via computer), does the multimedia help people to learn? If so, why? This paper examines the theory that it is not just multimedia, but multimedia that encourages elaborative encoding processes, that can make it easier to learn information.

Multimedia refers to the simultaneous presentation of information using more than one mode of information transmission. Media include text, graphics, animations, photographs, video, sounds, and auditory words. Multimedia are used to present information when your computer shows you a textual message and simultaneously plays a tone to tell you that an error occurred.

Encoding processes refer to the translation of physical, modal information into internal, cognitive representations. Encoding occurs, for example, when you see the letters "c," "a," "t" and translate them into the familiar word "cat." Elaborative encoding can be thought of as an encoding process that enriches a stimulus, therefore making it easier to store and retrieve the stimulus. For example, if you see the letters "c," "a," "t," translate the letters into the word "cat," then store an image of your cat Fluffy, you will probably find it easier to learn and recall the letters "c," "a," "t." Presenting information via multimedia, such as showing the word "cat" with a drawing of a cat, may encourage learners to perform more elaborative processing on the information.

If multimedia helps people to learn, it is difficult to determine whether it is the multiple media, the spontaneous elaborative encoding processes that the multiple media can encourage, or both factors that are most responsible for learning benefits. This paper examines theoretical positions and empirical results to support the theory that it is the elaborative encoding processes, rather than the multiple media alone, that can make it easier to learn information that is presented via multimedia.

This examination is important because the use of multimedia to present information for educational purposes is increasing rapidly. One of the best examples is the use of multimedia in computer-based tutorials. This increase appears to be fueled by several factors. First, the cost of multimedia-enabled computers is decreasing rapidly into price ranges that are suitable for the home and school markets. For example, very well-equipped multimedia-enabled machines are now available for less than \$2,000 (Calica, 1994; Wodaski, 1994). Second, learners prefer to have multimedia in their educational situations (e.g., Bosco, 1986; Bryant, Brown, Silberberg, & Elliot, 1980; Fletcher, 1989, 1990; Holliday, Brunner, & Donais, 1977; Rigney & Lutz, 1976; Samuels, Biesbrock, & Terry, 1974; Sewell & Moore, 1980). Third, and most importantly, people believe that educational multimedia improves learning. One set of statistics that is frequently cited (e.g., "Eloquent Idea," 1992; Hofstetter, 1994; "The Interactive Advantage," 1990) to justify using multimedia for educational purposes is that "People generally remember 20% of what they hear, 30% of what they see, [and] 50% of what they hear and see ..." (Treichler, 1967, p. 15). Unfortunately, Treichler's very compelling statistics are not based on empirical research.

If multimedia that encourages elaborative encoding processes can improve learning, then this idea has important implications for the design of educational software. For example, designers of computer-based tutorials can select media and learning activities for their elaborative processing properties rather than for their entertainment value. Expensive videos that are entertaining, but do not promote elaborative processing of the target information, can be eliminated. The designers can identify and use only media and activities that help the learner to learn. This approach should improve learning while decreasing the cost of developing computer-based tutorials.

This paper:

- (1) Describes the inconsistent effects of multimedia on learning.
- (2) Describes theories of learning and cognition that relate to elaborative encoding.

(3) Examines whether elaborative encoding can reasonably explain the inconsistent effects of multimedia on learning.

Chapter 2 Effects of Multimedia on Learning

This chapter describes studies that examined the effects on learning of using multimedia to simultaneously present mostly redundant information (e.g., text and illustrations) to learners. The studies support the conclusion that the effects of multimedia on learning are inconsistent.

Multimedia Helps People to Learn

The following studies suggest that presenting mostly redundant information using simultaneous, multimedia can help people to learn the information better than presenting the same information using a single medium. The studies are organized into categories that describe the media that were used to present the information in the studies.

Text and Illustrations

Levie and Lentz (1982) reviewed the literature on the effects of illustrations on learning textual information. The researchers examined over 55 experiments that used meaningful, connected, written text and experimenter-provided representational pictures (as opposed to charts, graphs, or diagrams). The textual materials included children's stories and science text. The illustrations included line drawings and color photographs. The learners differed in age levels (but most were elementary school age) and reading abilities. The experiments used a variety of measures of learning, including free recall, cued recall, and comprehension. In a typical experiment, the participants read the learning materials (with or without illustrations), then completed the learning test. Levie and Lentz (1982) concluded that illustrations improved the learning of textual information that was shown in the illustrations. The average learning improvement was 36%, a 0.5 standard deviation improvement of the learning performance of the text alone groups.

Text and Animated Graphics

Baek and Layne (1988) asked high school students to complete a computer-based tutorial on calculating average speed when given the distance traveled and the travel time. Each student learned in one of three conditions: (1) text alone, (2) text with still graphics, or (3) text with animated graphics. Each student controlled his or her progress through the tutorial. Students could move backward or forward in the tutorial. The graphics organized the textual material on the computer screen into categories for distance, traveling time, and speed. The animated graphics were a dashed line that was drawn at a speed that was related to the result of the average speed calculation. During the tutorial, the students completed several sample problems. Learning performance was based on an immediate test that included multiple-choice questions, a short-answer question, and 17 calculation problems. The experimenters calculated a single, summed test performance score for each participant. The experimenters found that adding animations to the text improved learning performance compared to adding still graphics to the text or compared to the text alone. Also, the still graphics with text group outperformed the text alone group.

Rieber (1989, 1990) created computer-based instruction on Newton's laws of motion that presented information via textual and graphic chunks. Fourth- and fifth-grade students learned the information in one of three conditions: (1) text alone, (2) text and static graphics, or (3) text and dynamic graphics. After each of the four instruction segments, the students answered multiple-choice questions about the segment. The students also interacted with a simulation showing the effects of forces on the motion of a "starship" in a gravity-free environment. Then the students completed a learning test that was composed of 26 multiple-choice questions. The experimenter also measured how long it took the students to answer each question. The students who saw text and dynamic graphics scored higher on the learning test than the students who saw text alone or text and static graphics. The experimenter found no differences in response time between the students in each group. In a similar study, Goldstein, Chance, Hoisington, and Buescher (1982) showed a 10-minute long movie clip (dynamic images) or 60 freeze frames (static images) from two different movies to college students. The researchers asked the students to try to remember the contents of the dynamic or still images. The researchers measured learning by asking the students

to complete a recognition test that used targets and distractors from the same kind of images that the students studied (dynamic or static). The study found that recognition accuracy (computed as d') for dynamic video scenes was better than that for static video scenes.

Audio and Audio-Visual

Barrow and Westley (1959) prepared four 15-minute long auditory (radio) and auditory-visual (television) programs that had very similar content. The writer for the programs included the same factual information in each program and maximized the effectiveness of each program. The researchers presented the four 15-minute long programs to 228 sixth-grade students. The students were separated into high, medium, and low IQ scorers on the California Test of Mental Maturity. Equal numbers of each group of IQ scorers were assigned to each of two groups of students in each classroom. One group of students in each classroom received the television presentation. The other group of students received the radio presentation. Sometimes the students participated in a 7.5-minute long, teacher-led discussion of the information in the presentation before completing an immediate, multiple-choice fact recall test. Other times, the students participated in the discussion after completing the immediate test. Finally, six weeks after the last presentation, the students completed a multiple-choice fact recall test for information from all four presentations.

Students recorded higher immediate test recall scores when they (1) received television presentations rather than radio presentations, and (2) when they had higher IQ scores. The discussion groups before or after the immediate tests did not affect learning performance. None of the interactions was statistically significant. On the delayed recall test, the researchers found no difference between students in the television or radio presentation groups. Students who scored higher on the IQ test performed better than other students. Also, the learning performance scores from students at some schools were better than the scores from students at other schools.

The most pertinent finding from the Barrow and Westley (1959) study is that, on the immediate test, the students who saw and heard the television programs recognized more facts than the students who only heard the radio programs. Other studies that measured fact recall (Frank, 1955; Greenfield, 1984; Nelson, 1949; Nelson, Moll, & Jaspen, 1950; Nelson & VanderMeer, 1955; Wetstone & Friedlander, 1974) obtained similar results. In a related study by Hayes, Kelly, and Mandel (1986), three- to six-year old children made more comprehension and recall errors when retelling the story after they heard the story (radio condition) than after they heard and saw pictures of the story (television condition).

Beagles-Roos and Gat (1983) presented auditory (radio) and auditory-visual (television) versions of the same 10-minute long story to elementary school children. As in the studies described above, when retelling the story, children in the television condition recalled more story details than children in the radio condition. In addition, children in the television condition were better able to put in correct order pictures related to the story.

Menne and Menne (1972) asked 36 third-grade children to recall three different, simple, unfamiliar, 22-word, four-line verses that were presented via sound alone, sight alone, and both sight and sound together. The researchers used a videotape to make the presentations. After each presentation, the researchers asked the children to recite back as much of the verse as they could recall. The researchers successively repeated each treatment-test combination three times for each child. The children recalled more words when they saw and heard a verse than when the children only saw or only heard a verse. These results are consistent with similar studies by Hartman (1961a, 1961b). Also, for single media, the children recalled more words when the children saw a verse than when the children heard a verse.

Pezdek, Lehrer, and Simon (1984) presented two short, unfamiliar stories to 96 third-grade and sixth-grade children. One group of children read one story and heard an auditory (radio) version of the other story. The other group read one story and saw and heard an auditory and animation

(television) version of the other story. After reading or being presented each story, the children answered comprehension and sentence recognition questions about the story. The study allowed the researchers to compare performance in the reading, radio, and television conditions. The children's comprehension and sentence recognition performance was about the same in the television and reading conditions, and this performance was better than in the radio condition. So, children learned better when they saw and heard an auditory and animation (television) version of a story than when they heard an auditory (radio) version of a story.

Mayer and Anderson (1991; experiment 2b) created three different types of explanations for how a bicycle pump works. The three explanation types were (1) auditory words, (2) silent animation, or (3) auditory words with animation. Mechanically naive college students were randomly assigned to each explanation type. The explanations were 30 seconds or less in length. The participants repeated the assigned explanation three times. After the third explanation, the participants completed four problem-solving questions (e.g., "What could be done to make a pump more effective, that is, to move more air more rapidly?"). On the problem-solving test, the participants who heard and saw the auditory words with animation performed better than the participants who heard the explanation or saw the animated explanation. Similar results were obtained in a subsequent study (Mayer & Anderson, 1992).

Text, Audio, and Illustrations

Severin (1967) asked seventh-grade students to learn lists of 15 animal names under one of several conditions: (1) text only, (2) audio only, (3) combined text and audio, or (4) combined audio and pictures. Each visual stimulus was presented for three seconds. After being presented with all 15 stimuli, the students completed recognition tests that used the same media that were used during learning. So, if a student learned the list using audio only, the student was tested using audio only. Though not tested statistically, learning performance in the combined audio and pictures condition was dramatically better than in the audio only condition. Learning in the combined text and audio condition was better than learning in the audio only condition. So, learning in the multimedia conditions was better than learning in the single media conditions. Severin (1967) also found that learning performance in the combined audio and pictures condition was better than in the combined audio and text condition. Learning in the text only condition was better than in the audio only condition. This last result was consistent with the findings of Menne and Menne (1972) and Van Mondfrans and Travers (1964) who also found that when the same information was presented visually or via audition, the information was learned better in the visual condition.

Overall, the results of the above studies suggest that presenting mostly redundant information using simultaneous multimedia can help people to learn information better than presenting the same information using a single medium. Multimedia can help people to learn. The improvement to learning seems to be especially strong when the multimedia includes both verbal and pictorial stimuli (e.g., Baek & Layne, 1988; Barrow & Westley, 1959; Beagles-Roos & Gat, 1983; Hayes, Kelly, & Mandel, 1986; Levie & Lentz, 1982; Menne & Menne, 1972; Severin, 1967). Also, adding animated pictures to text appears to improve learning better than adding static pictures (e.g., Baek & Layne, 1988; Goldstein, Chance, Hoisington, & Buescher, 1982; Rieber, 1989, 1990). Finally, for single media, it appears that visual verbal information (e.g., text) is learned better than auditory verbal information (e.g., Menne & Menne, 1972; Sewell & Moore, 1980; Severin, 1972; Van Mondfrans & Travers, 1964).

Multimedia Does Not Help People to Learn

The studies described above suggest that presenting roughly the same information using simultaneous multimedia can help people to learn the information. However, other studies show that presenting information via multimedia may not help people to learn. In fact, sometimes (e.g., Palmiter & Elkerton, 1991) multimedia may actually decrease learning compared to presenting information using a single medium.

Text and Illustrations

In their review of the literature, Levie and Lentz (1982) concluded that illustrations helped children learn information that was described in the text and shown in illustrations. These researchers also concluded that illustrations did not help children learn information that was described in the text but not shown in illustrations.

Text and Animated Graphics

Rieber (1989, 1990) used computer-based tutorials to teach fourth- and fifth-grade children about Newton's laws of motion. The students completed one of three different kinds of computer-based tutorials: (1) text alone, (2) text with static graphics, or (3) text with dynamic graphics. When the children did not practice with the information they were learning (e.g., answer questions on the section they had just studied and interact with a supportive simulation), there were no differences in scores on a multiple-choice test.

Text and Audio

Severin (1967) found no differences in recognition when seventh-grade students learned lists of animal names using text only versus combined text and audio. In a related study, Barron and Kysilka (1993) asked college students to use one hour to complete a self-paced, computer-based tutorial on a topic with which they were unfamiliar (compact disk—read only memory), but in which they were interested (the students were enrolled in an educational technology course). One group of students completed the tutorial using only text. Another group of students completed the tutorial using text with completely redundant audio. After completing the tutorial, the students answered objective questions about the information they had learned. The study found no differences between the groups.

Van Mondfrans and Travers (1964) arranged for college students to learn lists of nonsense syllables, common words, or partial sentences. The students learned the stimuli under each of the following conditions: (1) text presentation, (2) auditory presentation, or (3) combined text and auditory presentation. So, the students learned one list of 16 nonsense syllables that was presented via text, another list of 16 nonsense syllables that was presented via sound, and a third list of 16 nonsense syllables that was presented via text and sound. The students repeated the same pattern for the lists of common words and partial sentences. After each list presentation, the students wrote down as many of the items as the students could recall in 1.5 minutes. The researchers presented the list and test repeatedly until the student got two consecutive trials correct or the student completed 10 trials on the list. The researchers measured the number of errors made by each student until one of the criteria were attained. The study found no learning differences between the text condition and the combined text and auditory condition. So, the Severin (1967) and Van Mondfrans and Travers (1964) studies found that adding a redundant auditory verbal medium to a textual presentation did not improve learning. The Van Mondfrans and Travers (1964) study also found that learning performance in the auditory condition was worse than learning performance in the text condition and the combined text and auditory condition.

Audio and Audio-Visual

Beagles-Roos and Gat (1983) showed that elementary school children recalled explicit story content equally well in auditory only (radio) and auditory-visual (television) conditions. However, the children in the radio condition performed better on verbal learning measures such as accurately recalling expressive language from the story (e.g., "leopard of the terrible teeth") and drawing inferences from the verbal story information. The children in the television condition performed better on recall of audio-visual story details, ability to put in correct order pictures related to the story, and ability to make inferences based on actions in the story. Pezdek, Lehrer, and Simon (1984) found that comprehension performance was the same for elementary school children who read illustrated stories or heard and saw animated stories with an auditory soundtrack.

Palmiter and Elkerton (1991) taught adults computer user-interface steps by (1) procedural textual instructions on the computer screen, (2) an animated demonstration of the steps on the computer screen, or (3) combined animated demonstration and auditory verbal procedural instructions. The participants received the training on how to perform a task, then performed the task independently. The participants repeated the training until they performed the task correctly twice in a row. Then the study participants completed two tests of the same or very similar computer-interface steps. On the immediate test, the animated demonstration-only group was as accurate as the animated demonstration-combined with auditory verbal procedures group, and both groups were more accurate than the text only group. The addition of the auditory verbal medium did not appear to improve immediate learning. However, on the seven-day delayed test, the text-only group was more accurate than both animated demonstration groups. It appears that the group that learned using one medium (text only) learned better than the group that learned using two media (animated demonstration and auditory verbal procedures).

Text, Audio, and Illustrations

Sewell and Moore (1980) created several different versions of information on how to use a college library. The versions were: (1) text alone—a seven-page booklet, (2) audio alone—an audio recording of someone reading the text, (3) text with cartoons—an 18-page booklet with simple cartoon embellishments, and (4) audio with cartoons—an audio recording of someone reading the text cued to slides of the simple cartoons. The researchers randomly assigned college students to each version and told the students that they would be tested on the information contained in the materials. The researchers measured learning comprehension via a 25-item multiple-choice test on the verbal information. The study found no difference in learning performance for the students in the text alone, text with cartoons, and the audio with cartoons conditions. The students in the text alone and text with cartoons conditions scored higher on the comprehension test than the students in the audio alone condition.

The results of the above studies suggest that presenting mostly redundant information using simultaneous multimedia does not help people to learn the information compared to single medium presentations of the information. This appears to be especially true (e.g., Barron & Kysilka, 1993; Severin, 1967; Van Mondfrans & Travers, 1964) when the multimedia are both verbal (e.g., text and audio) and the single medium is verbal (e.g., audio). However, other studies that did not use all verbal conditions (e.g., Levie & Lentz, 1982; Palmiter & Elkerton, 1991; Pezdek, Lehrer, & Simon, 1984; Rieber, 1989, 1990) still found that multimedia often does not improve learning. Furthermore, multimedia can actually (e.g., Palmiter & Elkerton, 1991) decrease learning.

Chapter Summary

So, sometimes multimedia helps people to learn, and sometimes multimedia does not improve learning. The following section describes how one kind of cognitive processing of information, called elaborative encoding, may help to explain the inconsistent effects of multimedia on learning.

Chapter 3 Learning, Cognition, and Elaborative Encoding

This chapter describes basic learning processes, elaborative encoding, and a high-level theory of cognition. The focus of this chapter is explaining why elaborative encoding may help people to learn. This learning advantage may explain the inconsistent results of the studies that examined the effects of multimedia on learning.

The learning processes describe the fundamental ways that people are believed to receive, store, and retrieve information. Information that is processed elaboratively may be learned better than information that is not. John Anderson's Adaptive Control of Thought framework (1976, 1983a, 1983b, 1993) provides a theoretical explanation for how these learning processes, especially elaborative encoding, may work.

Learning

Learning can be defined as "the act of deliberate study of a specific body of material, so that the material can be retrieved at will and used with skill" (Norman, 1982, p. 3). Since learning is a cognitive process that occurs inside people's brains, learning is usually measured indirectly through performance on a variety of tests. For example, a free recall test measures how many items a person can remember from a list. A recognition test measures how many items a person recognizes from a prior learning session. A problem-solving test measures a person's ability to apply prior knowledge in a new way. These indirect measures of learning have disadvantages, however. The primary disadvantage is that performance on a learning test may not reflect how much information the person actually learned. This occurs, for example, when test questions are difficult for the test-taker to understand or the test questions do not cover the information that the test-taker studied. Poor performance on such a test does not mean that the test-taker learned very little information; it may mean that the test of learning is flawed. Nonetheless, tests of learning performance are a reasonably good way to measure the cognitive learning process, especially if the tests are carefully constructed to reflect the learner's abilities and the information that was studied.

Learning is thought to occur via the interaction of three basic cognitive processes. These processes are encoding, storage, and retrieval. Encoding is the process of translating a stimulus into a format that can be stored in the cognitive system (Best, 1992). Storage is the process that retains the encoded information in our memory. This paper emphasizes encoding into long-term, permanent, memory. Retrieval is the process of recovering the stored, encoded information. All three processes are interrelated. For example, since we cannot directly measure how information is encoded, we use the indirect method of asking people to retrieve encoded information. By manipulating the information that is presented, and measuring how accurately and quickly information is retrieved, we can get a better understanding of how information is encoded. So the ability to retrieve information affects how we believe the information may be encoded. The easier it is to retrieve information, the better we believe the information is encoded.

Encoding

A stimulus can be encoded in a variety of ways, including representations that are visual, spatial, acoustic, and semantic. It also appears that people have some control over how they encode a stimulus. The following sections describe studies that show that, when learning information, people use different encoding techniques.

Evidence for Visual Encoding

Baird, Clark, and Baird (1967) used a technique called "false recognition" to find empirical support for the existence of visual codes in long-term memory. The experimenters presented to their study participants drawings of 16 common objects, such as a cup. Each drawing was shown for two seconds. The participants' recognition memory was tested by showing groups of 11 randomly ordered drawings of each object. One drawing in each group was the original drawing. The other 10 drawings in each group varied in their degree of visual similarity to the original

drawing. The similar drawings were created by drawing 100 variations of an original drawing, asking 10 people to use a nine-point scale to rate the degree of visual resemblance of each drawing to the original drawing, then selecting 10 of the 100 drawings that represented five different degrees of similarity.

Participants performed the recognition test immediately after seeing the original drawings, two hours later, two days later, or two weeks later. The experimenters found that participants tended to falsely recognize drawings (i.e., incorrectly identify drawings as the original drawing) that were highly similar to the original drawing. This result supports the idea that the participants visually encoded the drawings.

Frost (1972) presented to participants drawings of 16 common objects to study, one at a time. Fifteen minutes after seeing the drawings, the participants performed a forced-choice (e.g., "Was this one of the items you studied?"), timed (e.g., "as quickly as you can") drawing recognition test. The participants were asked to report that a drawing of an object had been studied if the tested drawing showed the same object, but the object was drawn differently from the original drawing (e.g., the object was drawn from a slightly different perspective).

If the participants encoded the drawings purely verbally, then there should be no difference in reaction time to the drawings shown at a slightly different perspective because the drawings have the same name. In fact, participants responded an average of 180 milliseconds faster to drawings when the drawings were identical to the original than when the drawings were slightly different. This result suggests that the participants encoded a visual representation of the drawn objects rather than the verbal object names.

Additional support for the existence of visual encoding comes from a series of studies by Kosslyn (e.g., Kosslyn, 1973, 1975, 1976; Kosslyn, Ball, & Reiser, 1978; Kosslyn & Pomerantz, 1977). These studies support the idea that people can encode an exact, analog, visual image of a stimulus. For example, in one study (Kosslyn et al., 1978) the researchers asked participants to memorize and draw a simple map containing six objects until the participants drew the map nearly perfectly from memory. Then the researchers read the name of one of the objects on the map, asked the participants to mentally picture the entire map, and focus on the named object. After a five-second delay, the researchers read the name of the second object and asked the participants to mentally scan from the first imagined object to the second object, then press a key when they were at the second object. The researchers repeated this technique with a variety of object pairs. If the participants maintained an analog representation of the map, then the further the object pairs were located from each other, the longer it should take to mentally scan from the first object to the second object. The results of the study supported this hypothesis. People can encode an analog visual image of a stimulus (also see Cooper & Shepard, 1973 and Shepard & Metzler, 1971).

Evidence for Spatial Encoding

Kerr (1983) asked sighted and congenitally blind participants to learn the spatial layout of seven simple geometric figures that were on a board. For the blind participants, the figures were raised so the figures could be felt. After the participants learned the layout, the experimenters asked them to "focus" on a specific geometric figure. Then the experimenters read the name of another geometric figure. The participants' task was to imagine a raised dot traveling from the first geometric figure to the second geometric figure. When the dot arrived at the second geometric figure, the participants pressed a button. It is likely that congenitally blind participants could not encode the information visually, but they could encode it spatially. The study results showed that, for both sighted and congenitally blind participants, the greater the spatial distance between the two geometric figures, the longer it took to press the button. The results provide evidence for spatial encoding of information.

Santa (1977) found that geometric stimuli are encoded spatially, but verbal stimuli are encoded linearly. Santa presented to participants arrays of three geometric shapes (e.g., a drawing of a circle, a triangle, and a square). Then recognition accuracy and recognition time were tested using (1) identical arrays, (2) arrays with the same elements in a linear configuration, (3) arrays with different elements in the same configuration, or (4) different elements in a linear configuration. The participants were instructed to identify a test array as the same as a studied array when the same elements were in the test array, even if the order of the elements in the test array was different than a studied array. Recognition time was faster when the geometric shapes were the same and were in the same arrangement as a studied array than when the geometric shapes were the same, but were in a linear arrangement. This result suggests that the spatial information was encoded visually. When Santa replaced the geometric shapes with their names (e.g., replaced a drawing of a circle with the word "Circle"), participants showed shorter recognition times when the test items were shown in the same linear order in which the original spatial configuration of the shape names would have been read (e.g., left to right, top down such as "Circle Triangle Square") than when the shape names were shown in the same spatial configuration as a studied array. So verbal information was encoded and stored linearly (the way it was read).

Evidence for Acoustic Encoding

Nelson and Rothbart (1972) showed that people can encode acoustic information for textual words. The experimenters asked participants to learn two sets of paired-associates. In set 1, the stimulus word was a two digit number and the response term was a simple, common word (e.g., *27-tacks*, *81-jury*). The participants were asked to supply the response word when given the stimulus word. The participants practiced until they mastered the set 1 paired-associates. One month later, the participants were unexpectedly asked to return to the laboratory. The participants were first asked to generate each set 1 response term when given each set 1 stimulus term. Then the participants learned a second set of paired-associates. The set 2 stimulus words were the same as the set 1 stimulus words. Some stimulus words were paired with the same response words as in set 1. Some stimulus words were paired with a response word that was acoustically the same as the response word in set 1 (e.g., set 1 used *27-tacks*, set 2 used *27-tax*). Some stimulus words were paired with response words that were unrelated to the set 1 response terms (e.g., set 1 used *63-prey*, set 2 used *63-dough*). The experimenters recorded the time it took for the participants to learn the set 2 paired-associates.

For set 1 response words that the participants forgot on the unexpected, one-month delayed test, it took less time to learn new set 2 response words that were acoustically similar to the supposedly forgotten set 1 response words than to learn new set 2 response words that were unrelated to set 1 response words. These results support the idea that the participants acoustically encoded the set 1 response words.

Evidence for Semantic Encoding

Grossman and Eagle (1970) read to participants a list of 41 different words (e.g., "car"). After five minutes, the participants completed a recognition test that included nine words that were synonyms of nine words in the original list (e.g., "auto" is a synonym for "car") and nine words that were unrelated to words on the original list. Participants incorrectly identified an average of 1.05 of the nine unrelated words as being on the original list. But participants incorrectly identified an average of 1.83 of the nine synonyms as being on the original list. Since participants mistook synonyms for words from the original list, it appears that the participants encoded the meaning of the words as well as the words themselves. Anisfeld and Knapp (1968) obtained similar results in a related study.

Bousfield (1953) read to participants in random order a list of 60 words, one word every three seconds. The list was composed of 15 animal names (e.g., muskrat, panther), 15 professions (e.g., blacksmith, baker), 15 vegetables, and 15 names of people (e.g., Jason, Howard). After hearing the list, participants performed a free-recall test in which they wrote down as many of the

words as the participants could remember. The participants tended to recall together words from the same semantic category. The recall of a sequence of three or more words from the same semantic category was greater than that expected by chance. So, it appears that the participants semantically encoded the words.

Elaborative Encoding

Elaboration is one of the most effective ways to help encode information. Elaboration can be thought of as an encoding process that enriches a stimulus, therefore making it easier to store and retrieve the stimulus. For example, Bradshaw and Anderson (1982) asked participants to learn obscure information about famous people. There were two conditions. In one condition, the participants studied one fact (e.g., "Mozart made a long journey from Munich to Paris."). In the other condition, participants studied two more facts that were causally linked to the first fact (e.g., (1) "Mozart made a long journey from Munich to Paris" (the target sentence), (2) "Mozart wanted to leave Munich to avoid a romantic entanglement," (3) "Mozart was intrigued by musical developments coming out of Paris." The additional sentences served as verbal elaborations on the target sentence. One week later, the experimenters asked the participants to take a cued recall test of the target sentence (e.g., the participants were given the word "Mozart" and were asked to recall the target sentence). The percentage of target sentences correctly recalled was greater for target sentences with elaborating sentences than target sentences that were not elaborated. It appears that verbal elaborations created additional memory records that improved the ability of the participants to retrieve the original memory (the target sentence) (Anderson, 1994).

Dual Coding

It appears that pictures can encourage elaborative processing of verbal information. This technique is called dual coding (e.g., Paivio, 1971, 1986, 1991). According to dual coding theory, information is generally processed through one of two generally independent channels. One channel processes verbal information such as text or auditory words. The other channel processes nonverbal information such as illustrations and sounds. When information is processed through both the verbal and pictorial channels, recall is better than when information is processed through only one channel (e.g., Mayer & Anderson, 1991; Paivio, 1967, 1991; Paivio & Csapo, 1973).

The dual coding theory is supported by a wide variety of studies (e.g., Clark & Paivio, 1991; Mayer & Anderson, 1991; Paivio, 1967, 1971, 1986, 1991; Paivio & Csapo, 1973; Paivio & Foth, 1970). For example, Paivio and Csapo (1973) presented words and pictures in a random sequence that included presenting (1) a word twice, (2) a pictorial representation of the word twice, or (3) the word once and the picture once. A free-recall test found that learning was best when the word and its picture were each presented once. So, learning was best when the participants appeared to perform dual coding of the information.

Dual coding learning benefits can result even when physical stimuli are not presented. For example, Paivio and Foth (1970) asked college students to learn pairs of concrete nouns using either an imagery technique or a verbal technique. In the imagery technique, the students imagined and drew a picture linking both words. This technique encouraged the students to perform dual coded processing of the word pairs. In the verbal technique, the students developed and wrote down a word, phrase, or sentence that linked the two words. This technique did not encourage dual coding. Recall was higher with the dual coded imagery technique than with the verbal technique. Paivio and Csapo (1973) also found higher recall for concrete words that were read and imaged than concrete words that were read and pronounced. Bower (1972) asked participants to study 20 paired-associates (e.g., dog-bicycle). He asked half of the participants to simply study the word pairs and the other half of the participants to create a visual image in which both elements of the word pair were interacting (e.g., a dog riding a bicycle). On a cued recall test, memory was better for the group that imaged (recalled 75% of the items) than the group that did not image (recalled about 45% of the items). It appears that encoding interacting visual images improved memory for the textual information. Dual coding was better than verbal coding alone.

Effort

It appears that successful elaborative encoding is most likely to occur when the learner uses some effort to actively elaborate and encode the information. For example, Bower and Winzenz (1970) had groups of participants use different strategies to associate each response word with its stimulus word for 90 paired associates (three lists, 30 different pairs of unrelated concrete nouns (e.g., book-*cat*) per list). The learning strategies were: (1) repetition—rehearse each pair silently for the five seconds they were shown, (2) sentence presentation—when shown the word pairs in a sentence, use the sentence to remember the word pair (e.g., "The *book* fell on the *cat*"), (3) sentence generation—create a meaningful sentence or phrase that included the two words from each pair, and (4) imagery—form a mental image in which both words are interacting (e.g., a book falling on a cat). Immediately after seeing each of the three lists, participants took a cued recall test (half of the stimulus words from the list were presented, participants were asked to provide the matching response words) and a recognition test (participants were given a stimulus word and were asked to select the matching response word from a list of five candidates).

The repetition condition produced the worst performance for both tests. For the cued recall test, performance improved from repetition to sentence presentation to sentence generation to imagery. It appeared that the sentence provided by the experimenters in the sentence presentation condition helped participants link together the stimulus and response words. Using effort to create the sentence in the sentence generation condition appeared to cause the participants to more fully process and encode the relationship between the two words. This result is consistent with the generation effect (e.g., Bobrow & Bower, 1969; Jacoby, 1978; Slamecka & Graf, 1978) in which learning is better when participants actively generate the second word in a word pair than when participants passively read the word pair. Also, as expected (e.g., Paivio & Foth, 1970; Bower, 1972), the effects of dual coded, interacting imagery led to superior learning in the imagery condition.

Other studies support the idea that effort at encoding improves learning. For example, Walker, Jones, and Mar (1983) asked participants to read a series of paragraphs. Then the participants took a cued recall test in which they were asked to provide the last sentence of each paragraph. The last sentence in each paragraph included a word or phrase that related to an earlier sentence in the paragraph. This made the last sentence in each paragraph difficult to understand and encouraged the participants to use more effort to process the sentence. The experimenters found that when the last sentence was difficult to understand, and presumably required more effort to understand and process, the sentence was recalled better. Similarly, Kolers (1979) found that participants remembered upside-down sentences better than right-side-up sentences. Studies by Jacoby, Craik, and Begg (1979) and Salomon (1984) also support the idea that effortful processing increases elaborative encoding, and increased elaborative encoding improves learning.

Information Integration

Elaboration may also help the learner to integrate the stimulus with prior knowledge. For example, Stein and Bransford (1979) presented to participants ten sentences that described a simple, not integrated idea (e.g., "The fat man read the sign"), an irrelevant verbal elaboration that did not support integration of information (e.g., "The fat man read the sign that was two feet high"), or a relevant verbal elaboration that supported integration of information (e.g., "The fat man read the sign warning about thin ice"). After a short delay, the experimenters asked the participants to provide the missing adjective from sentences that described the simple, not integrated ideas (e.g., "The ____ man read the sign"). Participants who read the simple sentences recalled the adjective 42% of the time. Participants who read the sentences with irrelevant elaborations recalled the adjective only 22% of the time. But participants who read the sentences with relevant elaborations recalled the adjective 74% of the time. It appears that elaborations helped the learners integrate new knowledge (e.g., "The fat man read the sign") with prior knowledge (e.g., thin ice may be dangerous for a fat man), thereby improving memory for the new knowledge.

In a simple example, Frase (1975) found that learning was improved when Frase periodically asked participants to answer questions about the text they were reading. Other studies (e.g., Palmere, Benton, Glover, & Ronning, 1983; Pressley, McDaniel, Turnure, Wood, & Ahmad, 1987; Reder, 1979) also support the idea that elaborative encoding helps integrate new information with prior information. Some researchers (Alba & Hasher, 1983) believe that this integrated information is a unified mental representation composed of the stimulus, context, and prior knowledge.

So, it appears that elaborative encoding improves that ability of a learner to integrate new information with prior knowledge. Integrated information is easier to store and retrieve. The next section also suggests that information that is organized is learned better than information that is not organized.

Storage

Information appears to be organized when it is stored. For example, Tulving (1962) presented to participants a list of words that had no obvious relationships (no obvious categories). On repeated free recalls of the list, Tulving found that the participants tended to recall the words in clusters, and that these clusters tended to remain intact. So the participants appeared to organize the list of words. Rundus (1971) asked participants to rehearse list items out loud. Even though the items were presented in a random order, he found that items that were related tended to be rehearsed together. Jenkins and Russell (1952) found that when words from a list were randomly paired together, and several pairings of each word were provided, pairs with obvious associations (e.g., table-chair, black-white) tended to be clustered together during recall. Bousfield (1953) presented in a random order 60 words, 15 words each from four taxonomic categories (animals, professions, vegetables, and names). During free recall, the words were recalled in apparent category clusters. The results of these studies suggest that the participants stored and retrieved the words using organized groups.

Organizing information also appears to improve storage capacity. Mandler (1967; Mandler & Pearlstone, 1966) found that if people organized a list of words into up to seven conceptual, unnamed (e.g., these words go together) categories, more items from the list were recalled than when the participants did not organize the words into conceptual categories. Bower, Clark, Lesgold, and Winzenz (1969) and Cofer, Bruce, and Reicher (1966) found that telling participants the categories before they got a list of words increased the number of words recalled and the degree of clustering. Hudson (1969) gave to participants lists of words that could be organized into non-obvious categories (e.g., "globe," balloon, " and "button" can be placed in a category called "round;" "snow", "ivory," and "linen" can be placed in a category called "white"). The group of participants that was told the category names before getting the list recalled words by clusters more than the group that was told the category names after getting the list. These studies support the idea that information can be organized when it is encoded.

Organizing information also appears to improve the ability to store and retrieve information other than word lists. For example, students remembered more information from ambiguous auditory textual paragraphs when the paragraphs had a title that allowed the students to use prior knowledge to understand and organize the ambiguous paragraphs (for example, "Washing Clothes") than when the paragraph lacked a title (Bransford & Johnson, 1972). Seeing an explanatory cartoon before hearing an ambiguous textual passage improved learning the text compared to seeing an explanatory cartoon after seeing the text or seeing no cartoon (Bransford & Johnson, 1972). The explanatory cartoon may have allowed the participants to understand, organize, store, and retrieve the text.

So, it generally appears that when information is organized as it is being stored, learning is improved. This organizing function can be performed by semantic categories, titles, or even

pictures. The organization appears to make it easier for learners to encode, store, and retrieve the information.

Retrieval

The retrieval process can be thought of as generating candidate information, then searching organized cognitive information for the candidate (e.g., Rabinowitz, Mandler, & Patterson, 1977). There are two general kinds of retrieval activities—recall and recognition. To recall information, the person generates a candidate, then searches cognitive memory to recognize it (e.g., Hulse, Deese, & Eggeth, 1975). Recall occurs, for example, when you learn a list of words and then are asked to write down the words. To recognize information, the person searches cognitive memory to recognize it. The person does not generate candidates (e.g., Johnson, Dark, & Jacoby, 1985). Recognition occurs, for example, when you learn a list of words, are presented a list of words that include some of the studied words, and are asked to identify the words that you studied. Recognition performance is generally better than recall performance (e.g., Wessels, 1982).

The retrieval search is improved if the learning and retrieval contexts are similar. This often occurs in studies that unexpectedly find recall performance to be superior to recognition performance. For example, Watkins (1974) asked participants to learn pairs of five-letter and two-letter nonsense words in which each nonsense word was meaningless, but the combined seven-letter nonsense words were meaningful (e.g., SPANI-SH, INVOL-VE). On a recognition test, participants were given two-letter stimuli that included the two-letter, second half of studied nonsense word pairs (e.g., SH, VE). Recognition accuracy was only nine percent. On a later cued-recall test, participants were given the five-letter, first half of the studied nonsense word pairs (e.g., SPANI, INVOL) and were asked to recall the two-letter, second half of the word pair. Cued-recall accuracy was 67 percent. The explanation for these results is that there was a much better match between the information that was processed at encoding (e.g., SPANI-SH) and the cue that was used for retrieval for the cued-recall task (e.g., SPANI) than for the recognition task (e.g., SH). The encoding and retrieval contexts were more closely matched for this cued-recall test than for the recognition test. This phenomenon is known as encoding specificity (Flexser & Tulving, 1978, 1982).

So, retrieval is the process of finding cognitive information that is already stored. Since learning is usually measured by performance on learning tests, information that is easier to retrieve may show higher levels of learning on learning performance tests. Also, encoding specificity demonstrates that all three learning processes—encoding, storage, and retrieval—are interrelated. With encoding specificity, the way information is encoded affects the learner's ability to retrieve the information.

Elaborative encoding is a learning process in which a stimulus is enriched so that it is easier to encode, store, and retrieve. The next section describes a theory for how this process occurs and why it appears to improve memory.

Anderson's Theory of Cognition

John Anderson (1976, 1983a, 1983b, 1993) developed a theory of cognition that may explain how and why elaborative processing works. According to the Adaptive Control of Thought (ACT) theory, long-term memory consists of an interconnected network of propositions. A proposition is a fact, such as "The doctor is in the park" or a concept, such as "love" (Anderson, 1983b). The propositions serve as the nodes in the network. The nodes are connected to each other. For example, the propositional nodes "The doctor is in the park" and "The doctor is in the church" are connected by the concept "doctor." The proposition "The dog is in the park" is connected to the proposition "The lawyer is in the park" by the concept "park." As a person learns new information, the person adds interconnected propositions to the network (Anderson & Reder, 1979). At recall, the person can activate only a subset of the interconnected propositions. This means that the richer, more redundant, more interconnected a proposition is, the easier it will be to retrieve (Anderson & Bower, 1972, 1973; Anderson & Ortony, 1975; Foss & Harwood, 1975;

Jones, 1980). This is because a proposition that is elaborated will have more links to itself. When the person tries to retrieve the original proposition, more cognitive pathways to the target proposition are available to follow (Anderson, 1980; Anderson & Reder, 1979; Reder, 1980). Also, since a proposition may decay with time and disuse, a proposition that is easily and frequently activated will be easier to recall (Anderson, 1976, 1983a, 1983b, 1993).

According to Anderson's (1983a) theory, there are three ways that elaborative processing improves recall—inferential reconstruction, elaborative sources for activation, and redirecting activation. Inferential reconstruction is the process in which the learner uses recalled elaborations to reconstruct the studied information. The learner recalls the elaborations, re-processes them, and re-generates the studied information. Inferential reconstruction improves recall, but is also likely to result in a larger number of unintended recollections (intrusions) and slower recall time (Anderson & Reder, 1979; Bradshaw & Anderson, 1982; Reder, 1980). Inferential reconstruction appears to be a more significant influence on recall than elaborative sources for activation or redirecting activation (Walker, 1986). Elaborative sources for activation is the process in which the learner follows cognitive pathways from recalled elaborations to the studied information. Unlike inferential reconstruction, the learner does not build new cognitive pathways but follows existing pathways. This process depends on (1) the learner being able to recall the elaborations that the learner developed for the studied information (Anderson, 1976; Anderson & Bower, 1973; Anderson & Ortony, 1975) and (2) the learner retaining the pathways from the elaboration to the studied information (Walker, 1986). Redirecting activation is the process in which elaborations change the direction of cognitive activation from incorrect, interfering pathways to the correct pathways to the studied information.

According to Anderson (1983a, 1983b), elaborative processing that produces cognitive pathways leading to the studied information is called a relevant fan. Conversely, elaborative processing that produces cognitive pathways leading away from the studied information is an irrelevant fan (see, for example, Anderson, 1974). Relevant fans improve recall accuracy, but also increase recall time (Anderson, 1974). The reason for this unexpected increase in recall time is the spread of activation (e.g., Anderson, 1983b). When a learner tries to recall a learned proposition, the learner follows propositional network pathways to the target proposition (this is the activation process described above). When elaboration produces many pathways to the target proposition (a relevant fan), activation is spread across the elaborated pathways. As a result, it takes longer for the activation spreading from the various concepts in the network to intersect at the target proposition. It also takes longer to reach the threshold level of activation that causes the learner to decide that the target proposition was reached.

In ACT (Anderson, 1983a), recognition performance is better than recall performance because a recognition task only requires the learner to confirm that there is a pathway between the presented item and the list of learned items. With recall, the learner must repeatedly generate an item, then confirm whether there is a pathway from the generated item to the list of learned items.

So, elaborative encoding is effective because it enriches a stimulus, creating a larger number of relevant interconnections to the stored stimulus. Inferential reconstruction, elaborative sources for activation, and redirecting activation make an elaborated stimulus easier to retrieve. Since it is easier to retrieve, an elaborated stimulus shows higher levels of learning performance on tests of recall or recognition (Anderson & Bower, 1972, 1973; Anderson & Ortony, 1975; Bradshaw & Anderson, 1982; Foss & Harwood, 1975; Jones, 1980; Mayer, 1980; McDaniel, Dunay, Lyman, & Kerwin, 1988).

For example, in the Bradshaw and Anderson (1982) study that was discussed earlier, there were two conditions. In one condition, the participants studied one, unelaborated fact about a famous person (e.g., "Mozart made a long journey from Munich to Paris."). In the other condition, participants studied two other elaborated facts about the famous person. The elaborated facts were

causally linked to the first fact (e.g., (1) "Mozart made a long journey from Munich to Paris" (the target sentence), (2) "Mozart wanted to leave Munich to avoid a romantic entanglement," (3) "Mozart was intrigued by musical developments coming out of Paris"). One week later, a cued recall test for the target sentence found that recall was greater for target sentences with elaborating sentences than target sentences that were not elaborated.

Elaborative Encoding Summary

Elaborative processing is an (e.g., Bower & Winzenz, 1970) encoding process that enriches a stimulus, integrating the information with prior knowledge (e.g., Stein & Bransford, 1979), and increasing the number of interconnections it has with other information (e.g., Bradshaw & Anderson, 1982). These interconnections form a relevant fan to the information. The relevant fan makes it easier for the learner to retrieve the information because more information pathways can be followed to the target information. One of the most effective forms of elaboration is to encode a simple, concrete stimulus (such as the word "chair") in both verbal and pictorial forms. This technique is called dual coding (e.g., Paivio, 1971, 1991) and appears to be more effective than encoding a stimulus using verbal or pictorial encoding alone (e.g., Paivio & Csapo, 1973). Finally, encoding effort can improve the ability to learn information (e.g., Bower & Winzenz, 1970; Kolers, 1979; Walker, Jones, & Mar, 1983).

Chapter Summary

Learning is the cognitive process of encoding, storing, and retrieving information. Learning is measured indirectly via performance on tests of learning that use common retrieval processes such as recall or recognition. People can encode information a variety of ways, including visually, spatially, acoustically, or semantically. Elaborative encoding enriches a stimulus, increasing the number of interconnections available to prior knowledge, and making it easier to store and retrieve the stimulus. Elaborative encoding may also explain the inconsistent effects of multimedia on learning. Multimedia that encourages the learner to elaboratively process the information may improve learning compared to multimedia that does not encourage elaborative processing.

The next chapter re-examines the studies on the effects of multimedia on learning. This time, the studies are examined to determine whether elaborative encoding may reasonably explain the inconsistent effects of multimedia on learning.

Chapter 4 Elaborative Encoding and Multimedia Learning

Elaborative encoding may explain why multimedia helps people to learn in some situations but does not help people to learn in other situations. In particular, multimedia that encourages the learner to elaboratively process the information (for example, by using both verbal and pictorial codes, relevant motion, or by requiring the learner to use more effort) may improve learning more than multimedia that does not encourage elaboration. This chapter re-examines the studies reviewed in the previous chapter on the effects of multimedia on learning. The purpose of this examination is to determine whether elaborative processing may be a reasonable explanation for the inconsistent effects of multimedia on learning.

Multimedia Helps People to Learn

This section re-examines the studies that suggested that learning is improved when information is presented via somewhat redundant, simultaneous, multimedia.

Text and Illustrations

Levie and Lentz's (1982) literature review concluded that illustrations improved the learning of textual information that was shown in the illustrations. So, information that was shown both textually and pictorially was learned better than information that was shown only textually. This finding is consistent with studies (e.g., Mayer & Anderson, 1991; Paivio, 1967, 1991; Paivio & Csapo, 1973) that found learning benefits for situations that encouraged dual (verbal and pictorial) coding. It is possible that the illustrations provided another, richer way to connect the information to prior knowledge. The learners may have been able to connect the information to both verbal and pictorial cognitive nodes. This interpretation is supported by several studies (Levin, Bender, & Lesgold, 1976; Ruch & Levin, 1977) that found that pictures improved the recall of oral prose better than repetition of the oral prose.

Text and Animated Graphics

In Baek and Layne's (1988) study, high school students completed a computer-based tutorial that taught them how to calculate average speed when the students were given the distance traveled and the travel time. The three learning conditions were (1) text alone, (2) text with simple still graphics (column markers and a dotted line), or (3) text with simple animated graphics (column markers and a dotted line drawn at appropriate, relative speeds). The students in the text with animated graphics group recorded higher learning levels than the students who saw text alone or text with still graphics. It is possible that the motion in the animated graphics condition, although quite primitive, may have improved comprehension and encouraged the students to perform more elaborative processing than the students in the other conditions. Baek and Layne (1988) also found that the text with still graphics group outperformed the text alone group. The simple still graphics may have provided a structure that helped the students to organize the information. The finding that animated and still graphics improved learning is consistent with the previous suggestion that pictures may encourage elaborative processing of textual information.

Rieber (1989, 1990) performed studies in which elementary school children learned Newton's laws of motion using computer-based tutorials. The children also answered questions about the section they just completed and interacted with a helpful simulation. There were three tutorials: (1) text alone, (2) text and static graphics, or (3) text and dynamic graphics. The children who used the text and dynamic graphics tutorial showed higher levels of learning (as measured by 26 multiple-choice questions, including problems) than the students who used the text alone tutorial or the text and static graphics tutorial. In a similar study, Goldstein, Chance, Hoisington, and Buescher (1982) found that recognition memory for dynamic video scenes was better than that for static video scenes. It appears that relevant motion can increase the likelihood that learners will perform additional elaborative processing of the information to be learned.

Audio and Audio-Visual

In Barrow and Westley's (1959) study, sixth-grade children learned roughly the same information via auditory (radio) or auditory-visual (television) programs. The students who saw and heard the television programs recalled more facts than the students who only heard the radio programs. In another study (Hayes, Kelly, & Mandel, 1986), three- to six-year old children made more comprehension and recall errors when they heard a story (radio condition) than when they heard and saw pictures of the story (television condition). These results were repeated in other studies that measured fact recall (Frank, 1955; Greenfield, 1984; Nelson, 1949; Nelson, Moll, & Jaspén, 1950; Nelson & VanderMeer, 1955; Wetstone & Friedlander, 1974). So, adding visual stimuli to auditory information resulted in improved learning. It is possible that the visual media encouraged the learners to perform more elaborative processing of the information.

In the Beagles-Roos and Gat (1983) study, elementary school children were presented auditory (radio) and auditory-visual (television) versions of the same story. As in the studies described above, children in the television condition recalled more story details than children in the radio condition. The visual media may have encouraged elaborative encoding of the information. Also, the children in the television condition were better able to put in correct order pictures that were related to the story. This result appears to be consistent with the principle of encoding specificity. The children who learned using pictures did better on a test that used pictures.

The results of the Menne and Menne (1972) study were similar to those for the study by Beagles-Roos and Gat (1983). In the Menne and Menne (1972) study, third-grade children learned three different four-line verses. The researchers presented the verses using sound alone, sight alone, or sight and sound together. As in the Beagles-Roos and Gat (1983) study, the children recalled more words when they saw and heard a verse than when the children only saw or only heard a verse. Studies by Hartman (1961a, 1961b) obtained similar results. These results may be due to (1) the extra presentation provided by the audio-visual conditions, and (2) the elaborative processing that was encouraged by the visual stimuli. Also, the children recalled more words when the children saw a verse than when the children heard a verse. It appears that visual information is more elaborative than auditory information, especially for verbal recall.

Pezdek, Lehrer, and Simon (1984) presented short stories to third-grade and sixth-grade children using (1) auditory words, (2) text and illustrations, or (3) auditory words and animated illustrations. On tests of comprehension, learning performance was about the same in the condition with text and illustrations and in the condition with auditory words and animated illustrations. These performance levels were higher than those for the children in the auditory words condition. One explanation for the similar learning performance levels in the text and illustrations condition and the auditory words and animated illustration condition is that, since both conditions provided verbal and pictorial stimuli, both conditions encouraged dual coding of the information. The learning levels for these conditions may have exceeded those for the auditory words condition because the auditory words condition did not encourage elaborative dual coding.

Mayer and Anderson (1991; experiment 2b) created different versions of an explanation for how a bicycle pump works. The versions were: (1) auditory words, (2) silent animation, or (3) auditory words with animation. College students completed one version of the explanation, then answered several problem-solving questions on bicycle pumps. The students in the auditory words with animation condition outperformed the other students. The same researchers obtained similar results in another study (Mayer & Anderson, 1992). Since learning performance was highest in the only condition that provided both verbal and pictorial stimuli, these results may be due to the positive effects of elaborative dual encoding. The combination of the verbal and pictorial media may have allowed the students to better understand how a bicycle pump works and to develop a more complete cognitive model of bicycle pump operation.

Text, Audio, and Illustrations

In the Severin (1967) study, seventh-grade students learned lists of animal names using (1) text only, (2) audio only, (3) combined text and audio, or (4) combined audio and pictures. Learning was measured by recognition tests that used the same media used in the study condition. This technique minimized the effects of encoding specificity. Learning performance in the combined audio and pictures condition was much better than in the audio only condition. This result may have been obtained because the verbal and pictorial stimuli in the combined audio and pictures condition encouraged elaborative dual coding while the auditory words in the audio only condition did not. It is also possible that the extra presentation of the stimuli offered by the combined audio and pictures condition encouraged an additional rehearsal of the information and enhanced learning. Since Severin (1967) did not include a pictures only condition, it is not possible to determine whether learning was better in the combined audio and pictures condition compared to a pictures only condition.

Severin (1967) also found that learning in the combined text and audio condition was better than learning in the audio only condition. The addition of another verbal medium (the text) may have encouraged additional rehearsal of the material and improved learning. However, it is also possible that visual verbal material is more elaborative than auditory verbal material. In fact, Severin (1967) also found that learning performance in the text only condition was better than learning performance in the audio only condition. This result is consistent with the results of other studies (e.g., Menne & Menne, 1972; Sewell & Moore, 1980; Severin, 1972; Van Mondfrans & Travers, 1964) that found learning in a visual verbal condition was superior to learning in an auditory verbal condition.

Finally, learning performance in the combined audio and pictures condition was better than learning performance in the combined text and audio condition. The combined audio and pictures condition presented the information via verbal and pictorial media while the combined text and audio condition presented the information via two verbal media. Since learning performance was better in the combined text and audio condition, it is possible that the combination of verbal and pictorial information encouraged the students to perform elaborative dual coding of the information.

In general, it appears that elaborative encoding may be a reasonable explanation for the effectiveness of multimedia on learning. When multimedia encourages elaborative processing, learning appears to improve. For example, multimedia that uses verbal and pictorial information appears to be more elaborative than multimedia that uses only verbal information (e.g., Barrow & Westley, 1959; Beagles-Roos & Gat, 1983; Hayes, Kelly, & Mandel, 1986; Levin, Bender, & Lesgold, 1976; Mayer & Anderson, 1991; Paivio, 1967, 1991; Paivio & Csapo, 1973; Ruch & Levin, 1977; Severin, 1967). Multimedia that includes relevant, instructive motion may be more elaborative than multimedia that uses static pictures or no pictures at all (e.g., Baek & Layne, 1988; Rieber, 1989, 1990). It also appears that visual verbal information is more elaborative than auditory verbal information (e.g., Menne & Menne, 1972; Severin, 1967; Van Mondfrans & Travers, 1964).

So, multimedia may improve learning when the multimedia encourages elaborative processing of the information. To find additional support for this idea, we must examine the effects on learning when multimedia does not encourage elaborative processing. We should find that multimedia does not improve learning in these situations.

Multimedia Does Not Help People to Learn

The purpose for examining the following studies is to determine whether it is the elaborative encoding processes, rather than the multimedia, that appear to make it easier to learn information that is presented via multimedia. The following section re-examines the studies in which multimedia did not help people to learn.

Text and Illustrations

Levie and Lentz's (1982) review concluded that illustrations did not help children to learn information that was described in text but was not shown in accompanying illustrations. This result may be explained by elaborative encoding. Since illustrations were not available to encourage elaborative encoding of the textual information, that textual information was not learned as well as textual information that was accompanied by relevant illustrations. So, illustrations alone do not improve learning of textual information. The illustrations must be closely associated with the text so that the illustrations encourage elaborative processing of the textual information.

Text and Animated Graphics

In Rieber's (1989, 1990) studies, no differences in learning were found for elementary school students who practiced very little on computer-based instruction that was presented via text alone, text with static graphics, or text with dynamic graphics. The practice consisted of answering multiple-choice questions about the section they had just completed and interacting with a supportive simulation. It is possible that the lack of practice reduced the opportunities for the students to perform elaborative encoding on the information that was shown via text and graphics. Since no information was elaboratively encoded, the studies found no differences in learning for the three experimental conditions.

Text and Audio

Severin's (1967) study obtained no differences in recognition performance when seventh-grade students learned animal names using text only or combined text and audio. Since both conditions were verbal, it is likely that the students performed similar levels of verbal processing of the information. Neither condition was associated with a learning advantage because neither condition provided an opportunity for elaborative dual coding of the information. The study by Barron and Kysilka (1993) obtained similar results. In this study, college students completed a computer-based tutorial using text only or text with completely redundant audio. On an immediate test of learning, no differences were found between the groups. Finally, in the Van Mondfrans and Travers (1964) study, college students learned lists of nonsense syllables, common words, or partial sentences under the following conditions: (1) auditory only, (2) text only, or (3) combined text and auditory. Free-recall tests of learning found no differences between the text only condition and the combined text and auditory condition. Also, learning in the auditory only condition was worse than learning in the text only condition and the combined text and auditory condition.

These studies suggest that since multiple verbal media do not provide elaborative processing advantages, multimedia that provides verbal information does not improve learning compared to single media that provide verbal information. So, presenting information via multimedia does not necessarily enhance learning. To be effective, it appears that the multimedia needs to encourage elaborative processing of the information. The studies above suggest that adding supporting illustrations to verbal information may be one way to encourage elaborative processing of the information. The study by Van Mondfrans and Travers (1964) also suggests that visual verbal information is learned better (and is possibly more elaborative) than auditory verbal information (this result may also be due to the fact that visual verbal information allows people to review and control presentation rate better than auditory verbal information).

Audio and Audio-Visual

Beagles-Roos and Gat (1983) showed that elementary school children recalled explicit story content equally well in auditory only (radio) and auditory-visual (television) conditions. The results of other studies (e.g., Barrow & Westley, 1959; Hayes, Kelly, & Mandel, 1986; Levin, Bender, & Lesgold, 1976; Mayer & Anderson, 1991; Paivio, 1967, 1991; Paivio & Csapo, 1973; Ruch & Levin, 1977; Severin, 1967) suggest that this is an unexpected finding. Combined verbal-pictorial media are more often associated with better learning than verbal media alone.

However, it is also possible that the children in the Beagles-Roos and Gat (1983) study worked harder to understand the story in the auditory only condition than the children in the auditory-visual condition. This extra effort may have caused the students to increase their processing of the story information (e.g., Bobrow & Bower, 1969; Bower & Winzenz, 1970; Jacoby, 1978; Slamecka & Graf, 1978) and resulted in learning performance levels that were similar to the students who saw and heard the story. This explanation is questionable, though, since children in other studies that heard stories (e.g., Barrow & Westley, 1959; Hayes, Kelly, & Mandel, 1986) did not appear to expend more effort to understand and elaboratively encode auditory stories compared to auditory-visual stories.

The Beagles-Roos and Gat (1983) study also found that the children in the auditory only condition performed better on verbal learning measures than the children in the auditory-visual condition. This result may be due to the effects of encoding specificity. The children who learned the information in the verbal only (auditory) condition performed better on the verbal tests than the children who learned the information in the verbal-pictorial (auditory-visual) condition. This seems like a reasonable explanation because children in the auditory-visual condition also performed better on tests that measured their ability to put in correct order pictures related to the story.

The study by Pezdek, Lehrer, and Simon (1984) found similar performance on comprehension tests by elementary school children who (1) read illustrated stories, or (2) heard and saw animated stories with an auditory soundtrack. Since both conditions involved verbal-pictorial stimuli, it is possible that the children in both conditions performed elaborative dual coding, so there were no differences in learning performance.

Palmiter and Elkerton's (1991) study appears to support the idea that effortful encoding can improve learning. In this study, college students learned computer user-interface steps via (1) procedural textual instructions on the computer screen, (2) an animated demonstration of the steps on the computer screen, or (3) combined animated demonstration and auditory procedural instructions. Based on the prior studies that included verbal and verbal-pictorial conditions, the expected result is that the verbal-pictorial animated demonstration and auditory instructions condition would be associated with the highest learning levels. On an immediate test of learning, the students who saw the pictorial demonstrations outperformed the students who saw only text. One explanation for this result is that pictorial demonstration information was more elaborative than the verbal textual information.

Learning did not improve when auditory verbal procedures were added to the pictorial demonstration. So, another explanation relates to attention. It is possible that the learners focused on the eye-catching movement in the dynamic, pictorial, procedural demonstrations and ignored the auditory, verbal, procedural instructions. For example, on the seven-day delayed test, learning performance in the verbal text condition was higher than either pictorial demonstration group. Learning was higher in the condition with one verbal medium (displayed text) than in the condition with both verbal and pictorial media (auditory verbal instructions and pictorial animated demonstration). This unexpected result may be due to encoding effort. The seven-day delayed test required the learner to access information that had been encoded well because information that was encoded well would be more likely to be available after a week than information that was not encoded well. It is possible that the students in the text only condition found it difficult to understand the procedures and had to expend more effort than students in the other conditions to understand and encode the instructions well. The students in the demonstration conditions may have passively watched the highly salient animation, ignored the auditory verbal information, and encoded the procedure less well.

So, it appears that the benefits of elaborative dual (verbal and pictorial) encoding can be mitigated by effortful encoding by the learner. Although learning appears to be superior in combined verbal-

pictorial conditions, encoding effort (and associated elaborative processing) can cause learning performance in verbal conditions to equal that in combined verbal-pictorial conditions.

Text, Audio, and Illustrations

In the study by Sewell and Moore (1980), college students completed a computer-based tutorial in one of the following conditions: (1) text alone—a seven-page booklet, (2) audio alone—an audio recording of someone reading the text, (3) text with cartoons—an 18-page booklet with simple cartoon embellishments, and (4) audio with cartoons—an audio recording of someone reading the text cued to slides of the simple cartoons. Learning performance was the same for students in the text alone, text with cartoons, and the audio with cartoons conditions. Adding illustrations did not improve learning. This result may have been obtained because the simple cartoon embellishments did not relate closely to the text but merely served as decorations (Levie & Lentz, 1982). As a result, the cartoons did not encourage the students to elaboratively encode the accompanying verbal information. The study also found that students in the text alone and text with cartoons conditions recorded higher learning scores than students in the audio alone condition. This result is consistent with other studies (e.g., Menne & Menne, 1972; Severin, 1967; Van Mondfrans & Travers, 1964) which found that learning from visual verbal information tends to be better than learning from auditory verbal information. It is possible that self-paced text allows learners to perform more elaborative encoding (and learn better) than machine-paced audio.

Chapter Summary

In general, it appears that elaborative encoding may be a possible explanation for the effects of multimedia on learning. Multimedia appears to improve learning when the media encourage elaborative encoding of the information. For example, combinations of textual or auditory verbal information and supportive, relevant illustrations appear to be more elaborative than textual or auditory verbal information that is presented together or alone (e.g., Barrow & Westley, 1959; Beagles-Roos & Gat, 1983; Hayes, Kelly, & Mandel, 1986; Levin, Bender, & Lesgold, 1976; Mayer & Anderson, 1991; Paivio, 1967, 1991; Paivio & Csapo, 1973; Ruch & Levin, 1977; Severin, 1967). Adding explanatory (but not procedural) motion to textual or auditory verbal information may be more elaborative than using static pictures or no pictures at all (e.g., Baek & Layne, 1988; Rieber, 1989, 1990). Regarding single media, visual verbal information appears to be more elaborative than auditory verbal information (e.g., Menne & Menne, 1972; Severin, 1967; Van Mondfrans & Travers, 1964).

Multimedia does not appear to improve learning when the media uses two versions of verbal information (e.g., textual and auditory verbal information) (e.g., Barron & Kysilka, 1993; Severin, 1967; Van Mondfrans & Travers, 1964) or when the multimedia uses illustrations that do not support the accompanying verbal information (e.g., Levie & Lentz, 1988; Sewell & Moore, 1980). It also appears that when learners expend effort to encode the information, learning performance improves (e.g., Bobrow & Bower, 1969; Bower & Winzenz, 1970; Jacoby, 1978; Kolers, 1979; Palmiter & Elkerton, 1991; Rieber, 1989, 1990; Slamecka & Graf, 1978; Walker, Jones, & Mar, 1983).

However, in some ways the elaborative encoding explanation for the effects of multimedia on learning may be considered to be a circular argument. In the preceding literature review, it was argued that whenever multimedia improved learning, it was because the multimedia encouraged the learner to perform elaborative encoding. When multimedia did not improve learning, it was because the learner did not perform elaborative encoding. To break out of this circular argument, we need an independent measure of elaborative encoding. For example, according to Anderson's (1976, 1983a, 1983b, 1993) ACT theory, elaboration produces a relevant fan of propositions that improve recall accuracy, but increases recall time (e.g., Anderson & Reder, 1979; Bradshaw & Anderson, 1982; Reder, 1980). So one candidate independent measure of elaborative encoding may be recall or recognition latency. The longer the latency, the greater the elaborative encoding.

Based on the preceding chapters and sections, we can draw the following conclusions:

- (1) The results of studies on the effects of multimedia on learning are not consistent. Presenting information via multimedia sometimes helps and sometimes does not help people to learn the information.
- (2) Elaborative encoding appears to improve learning. This effect appears to be especially pronounced when the elaborative encoding is intentional and conscious (e.g., when learners created sentences that used the studied words in Bower and Winzenz, 1970).
- (3) Some media seem to encourage spontaneous elaborative encoding more than other media. For example, when information is presented via text and accompanying pictures (verbal-pictorial conditions), learning is often higher than situations in which the information is presented via text and audition (verbal-verbal conditions). Relevant, supportive, animated motion also appears to improve learning of verbal information better than static pictures or no pictures at all.
- (4) When learners actively expend effort to understand, elaborate, and encode information, learning performance appears to improve. This effort may increase the amount of elaboration that the learner performs on the information, increasing the number of connections available to prior knowledge and improving the integration of the new information with prior knowledge.

So, elaborative encoding may be a reasonable explanation for the inconsistent effects of multimedia on learning. Multimedia alone does not improve learning. Rather, presenting information via multimedia that encourages elaborative processing of the information (e.g., when information is presented via both verbal and pictorial media versus two verbal media) appears to improve learning. This learning improvement is obtained because elaboration improves the ability of the learner to perform inferential reconstruction of the learned information (Anderson, 1983a). Inferential reconstruction is the process in which the learner uses recalled elaborations to reconstruct the studied information.

Chapter 5 Interpretation

I believe that multimedia can improve learning. However, this effect is most likely to occur when the multimedia:

- Are presented simultaneously—Presenting the information via different media at the same time seems to improve learning compared to separating the presentations in time (e.g., Baggett, 1984; Baggett & Ehrenfeucht, 1983; Mayer & Anderson, 1991).
- Show information that is closely related—Showing closely related, supportive information via different media appears to improve learning (e.g., Bransford & Johnson, 1972; Levie & Lentz, 1982; Peeck, 1974). Conversely, showing less related, less supportive information via different media appears to have no impact on learning or a negative impact on learning (e.g., Bahrack & Gharrity, 1976; Evans & Denney, 1978; Levie & Lentz, 1982; Samuels, 1967, 1970; Sewell & Moore, 1980).
- Use different processing channels (i.e., verbal and pictorial)—Providing opportunities for the learner to perform elaborative dual coding (Paivio, 1971; 1986; 1991) appears to have strong positive impacts on learning (e.g., Barron & Kysilka, 1993; Barrow & Westley, 1959; Beagles-Roos & Gat, 1983; Hayes, Kelly, & Mandel, 1986; Levin, Bender, & Lesgold, 1976; Mayer & Anderson, 1991; Paivio, 1967, 1991; Paivio & Csapo, 1973; Ruch & Levin, 1977; Severin, 1967; Van Mondfrans & Travers, 1964).
- Do not interfere with each other—Presenting information so that the information in one medium completely captures the learner's attention may decrease the likelihood that the learner will process the information from the other medium. For example, the animated demonstration in the study by Palmiter and Elkerton (1991) may have kept learners from processing the auditory verbal information that was being presented simultaneously.
- Are presented to learners with low aptitude or low prior knowledge in the domain—Using multimedia to provide more opportunities for the learner to connect new information to prior knowledge appears to be especially helpful when the learner is naive or has low aptitude (e.g., Blake, 1977; Kunz, Drewniak, & Schott, 1989; Mayer & Gallini, 1990; Wardle, 1977, cited in Levie & Lentz, 1982). Learners with high aptitude or high prior knowledge in the domain appear to be able to learn without the advantages of multimedia, possibly because these learners already have a rich set of prior knowledge to explain and connect the new knowledge.
- Are evaluated on learning measures that reflect the information presented for learning—Measuring learning using a metric that is tied to the information that was learned (e.g., verbal tests for verbal learning) results in learning improvements (e.g., Beagles-Roos & Gat, 1983).

I believe that, given the conditions described above, multimedia can help people to learn because multimedia can encourage elaborative encoding. Multimedia can improve the number of opportunities that learners have available to connect new information to prior knowledge (e.g., Palmere, Benton, Glover, & Ronning, 1983; Pressley, McDaniel, Turnure, Wood, & Ahmad, 1987; Reder, 1979). When the new information is integrated with prior knowledge, it is organized into the learner's existing cognitive structure of knowledge. This organization improves the ability of the learner to store and retrieve the information (e.g., Bransford & Johnson, 1972), resulting in improved learning.

Measures of Learning

However, the word "learning" can have many definitions. These definitions range from the biological ("a succession of changes in the neurological states that a given brain could enter, or compute, as a function of its experiences with certain types of stimuli" (Best, 1992, p. 20)) to the cognitive ("the act of deliberate study of a specific body of material, so that the material can be retrieved at will and used with skill" (Norman, 1982, p. 3)). The range includes very general definitions ("acquired wisdom, knowledge, or skill" (Berube, et al., 1982, p. 720)) and very specific definitions (the description of the learning situation characteristics, including the learner, learning activities, learning materials, and test of learning (Bransford, 1978)).

Most of the studies used to support the conclusions in the bullet list above are based on measures of cued recall, recall, and recognition. These measures reflect the learner's rote memory. However, I believe that "learning" should reflect not just rote memory, but the ability of the learner to meaningfully apply what was learned. This means that the learner cannot simply retrieve or recognize what was stored. The learner must interpret, manipulate, and apply the knowledge in a new, meaningful way.

I define "learning" using Donald Norman's (1982, p. 3) statement that learning is "the act of deliberate study of a specific body of material, so that the material can be retrieved at will and used with skill." Probably the best way to measure the ability of a learner to use knowledge "with skill" is to measure the learner's ability to solve problems that require more than the rote retrieval of learned information (e.g., not just recalling the procedures to solve a math problem). So, I believe that the best measure of this definition of learning is problem-solving transfer.

Problem-solving transfer can be defined as "solving problems that differ from anything in the learning materials" (Mayer, 1993, p. 260). For example, problem-solving transfer occurs when a learner completes a tutorial that describes how a simple system works (e.g., a bicycle pump), then answers questions that require the learner to use information that was not specifically provided in the tutorial (e.g., "Why does air enter a pump?"). This type of problem-solving transfer has been investigated extensively by Richard Mayer (e.g., Mayer, 1975, 1980, 1989a, 1989b, 1993; Mayer & Anderson, 1991, 1992; Mayer, Cook, & Dyck, 1984; Mayer & Gallini, 1990) using text and static illustrations.

Najjar Elaborative Encoding Theory

To be used as an effective explanation, elaborative encoding needs to be refined further. Elaborative encoding needs to be made into more of a theory. According to Stanovich (1992, p. 21), a theory is "an interrelated set of concepts that is used to explain a body of data and to make predictions about the results of future experiments." A theory must generate predictions that can be falsified. In response to this need, I generated the Najjar Elaborative Encoding Theory (NEET). The first draft of the theory is as follows:

- The concept of "elaborative encoding" is defined as cognitive processing of a stimulus that integrates the stimulus with prior knowledge.
- The concept of "learning" is defined as "the act of deliberate study of a specific body of material, so that the material can be retrieved at will and used with skill" (Norman, 1982, p. 3) (so the theory emphasizes meaningful learning, such as problem-solving, versus simple recall or recognition).
- The concept of "relevant encoding features of a stimulus" is defined as features that are related to the measure of learning (so, for example, color is a relevant feature of a stimulus if color helps to explain the information that is learned and measured).

- Elaborative encoding can be encouraged by presenting to the learner stimuli that are rich in possible relevant encoding features.
- Elaborative encoding is more likely to occur when the learner actively, consciously develops elaborations for the target information.
- Elaborative encoding improves learning because it builds a richer set of integrated memories compared to encoding that is not elaborative.

Needed Research

If we accept that (1) multimedia can improve learning by encouraging elaborative encoding, and (2) learning is measured by problem-solving transfer, then a research gap needs to be filled. Although there is a large body of studies that examine the effects of multimedia on cued recall, recall, and recognition, the number of studies looking at problem-solving transfer is relatively small (e.g., Baek & Layne, 1988; Mayer's work). To improve the effectiveness of multimedia instruction, the effects of other multimedia combinations, such as audio verbal instructions + video, on problem-solving transfer need to be examined.

These studies need to determine whether multimedia can provide elaborative encoding advantages (see the Najjar Elaborative Encoding Theory described above) to learners. For example, we can (1) try to keep the information the same, but manipulate the combinations of media to see if the media themselves offer elaborative encoding advantages (e.g., evaluate whether audio verbal + video is superior to audio verbal + text or audio verbal + static illustrations), and (2) manipulate active, conscious, elaborative encoding (e.g., ask the learner to answer intermittent questions that encourage elaborative encoding, such as "Why does ...?") to determine whether this technique improves learning. These studies will extend and validate the Najjar Elaborative Encoding Theory while also providing practical guidelines to educational multimedia user interface designers.

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Biography

Larry Najjar attended the College of the Holy Cross in Worcester, Massachusetts. He graduated with a BS in psychology in 1980. In 1983, he was awarded an MS in engineering psychology from the Georgia Institute of Technology in Atlanta, Georgia.

After graduating, Larry worked for Systems Research Laboratories in Hanover, Maryland. He designed the software and hardware user-interface for an advanced word processing and audio transcription work station. In 1984, he joined the IBM Corporation in Rockville, Maryland. Larry helped design the user-interface for the next-generation US air traffic control system, including the digital flight strips, keyboard, work station, and user warnings. In 1989, he transferred to Atlanta, Georgia, where he designed and tested user-interfaces for a wide variety of commercial applications.

Larry left IBM in 1993 to pursue his PhD in engineering psychology at the Georgia Institute of Technology. He is a graduate research assistant at the Georgia Tech Research Institute. On his current project, he is helping to design and build a wearable computer that provides multimedia training for poultry plant workers. For his dissertation, Larry plans to examine the effects of multimedia user-interface design on learning.

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